7
Conclusions and future work

In this work, a prototype system that is capable of performing 3D manipulation operations of virtual 3D objects using user's own hands directly, is demonstrated. The system tracks bare (that is, unmarked, uninstrumented) hands of the user and recognizes one-handed and two-handed static hand gestures in a non-contact way using passive computer vision techniques, in order to implement operations for manipulation of virtual 3D objects.

7.1
Contributions

Compared to existing approaches, this work brings about the following contributions:

1. 3D UNMARKED HAND TRACKING — A very inexpensive way to recover continuous 3D position of up to two unmarked hands in real time.

2. SPATIAL INPUT — implementation of a novel $2 \times 3 = 6$ d.o.f. spatial input device, using two stereo trackers based on the "Flocks-of-features" [35] hand tracking and Viola-Jones method [29] applied to hand detection and hand recognition, in order to implement state switching.

3. FREE-HAND SPATIAL MANIPULATION — implementing spatial operations on top of this novel input spatial device, thus enabling the user to manipulate virtual 3D objects using free-hand motions, without any need to put any extra hardware onto his hands.

7.2
Future work

Future work includes the following:

1. Increasing the working volume (workspace) where the user can move his hands by using wide-angle or fish-eye cameras.

2. Expanding the system to work in more diverse environments, for example by pointing the cameras *towards* the user, instead of having the cameras point just downwards as shown in Figure 6.1 on page 59. This would be convenient, for example, for notebook or desktop computer users, who could clip a stereo pair of cameras onto their notebooks' screens.

3. Increasing the expressiveness of direct manipulation by including fingers into the manipulation operations. This probably entails implementing some sort of model-based tracking, that is, using a parametric 3D hand model.

4. Increasing the expressiveness of direct manipulation by including *dynamic gestures* into manipulation operations. This entails implementing some sort of real-time dynamic gesture analysis, for example by using Hidden Markov Models (HMMs).

5. Increasing the robustness of one-hand and two-hand tracking, perhaps by implementing predictive filters like for example the Kalman filter.

6. Enriching the set of manipulation operations, especially by adding more complex, physically based manipulation and deformation operations, like "attract", "repel", "cut", "shear", "distort", "emboss", "drill", "abrade" and similar. Those operations, again, would be performed using just unmarked hands.

7. Developing appropriate spatial and topological data structures for the aforementioned manipulation and deformation operations.

8. Conduct appropriate usability studies.